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Foster-Miller
A QinetiQ Company

# UV-CURABLE AEROSPACE PAINT SYSTEMS

Presented by
Foster-Miller, Inc.

February 28, 2008

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| **28 FEB 2008** | | **00-00-2008 to 00-00-2008** |

| 4. TITLE AND SUBTITLE | 5a. CONTRACT NUMBER |
|---|---|
| **UV-Curable Aerospace Paint Systems** | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Foster-Miller, Inc.,350 2nd Avenue ,Waltham,MA,02451** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S) |
| | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES
**Surface Finishing and Repair Issues for Sustaining New Military Aircraft Workshop, February 26-28, 2008, Tempe, AZ. Sponsored by SERDP/ESTCP**

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | |
| **unclassified** | **unclassified** | **unclassified** | **Same as Report (SAR)** | **26** | |

# Development Team: UV Curable Aerospace Coatings

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- US Navy
  - Mr. Ed Lipnickas

# Aerospace Coatings

- Protective and decorative finishes for
  - Passenger aircraft
  - Military aircraft
  - Space vehicles

Estimated annual market of $100 M

# Total Aerospace Coatings Volume

- Primers/Topcoat 90%
- Specialty Coatings 10%

# The Need

- Airframe coatings used by the DOD have long dry-to-fly times
- Airframe coatings used by the DOD contain excessive toxic pollutants:
  - VOCs - solvents to adjust consistency
  - Heavy metals - particularly chromate corrosion inhibitors
- Problems with these ‘non-green’ coatings include:
  - Health problems
  - Expensive emission controls
  - Environmental regulations ban future use
- Alternative coatings that are available are deficient in:
  - Application method - cannot spray
  - Cure time/cure temperature
  - Performance - adhesion, corrosion prevention
- New coating materials are needed that are:
  - Safe, environmentally compliant
  - Meet or exceed current performance specifications

# Foster-Miller's UV Curable Coating

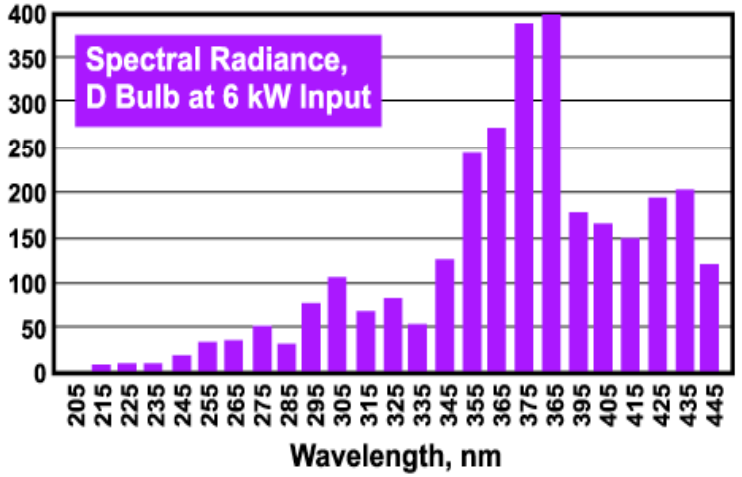
- Novel UV cure mechanism achieves rapid cure - reduces dry-to-fly time from days to minutes
- Family of resins - properties highly tailorable by changing resin backbone
- Environmentally compliant - No VOC's, HAP's or free diisocyanates
- Single-component product

# Accomplishments

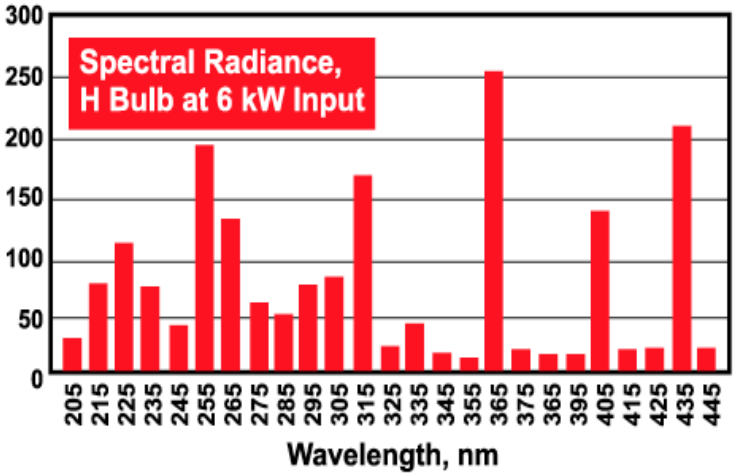
- Developed a variety of formulations with different properties as required by specific applications.
- Filled formulations were successfully cured in thickness ranging from 1-50 mils
- Multilayer application was successfully demonstrated up to 250 mils - layers were compatible and demonstrated good adhesion
- Scale-up - quantities have been scaled to the 25 gal level
- Gloss reduction when needed
- Uniform dispersion – resin system can be formulated and dispersed uniformly to ensure continuity of properties
- No voids or settling - coating is “frozen” in place by UV irradiation, repair is feasible
- Put together a vertically integrated team including suppliers, end users, and a manufacturer and convinced the community to obtain more funding

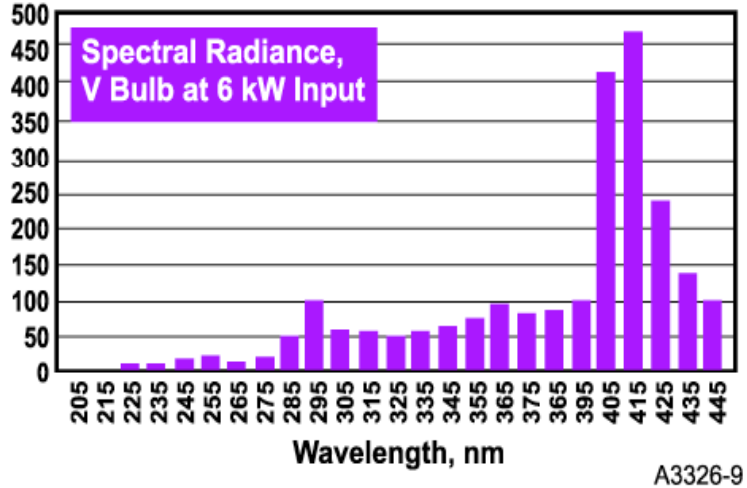
## *In-Depth Cure*

**UV light-producing bulbs are arranged in tandem to fully cure the coating test sample**




## *Surface Cure*

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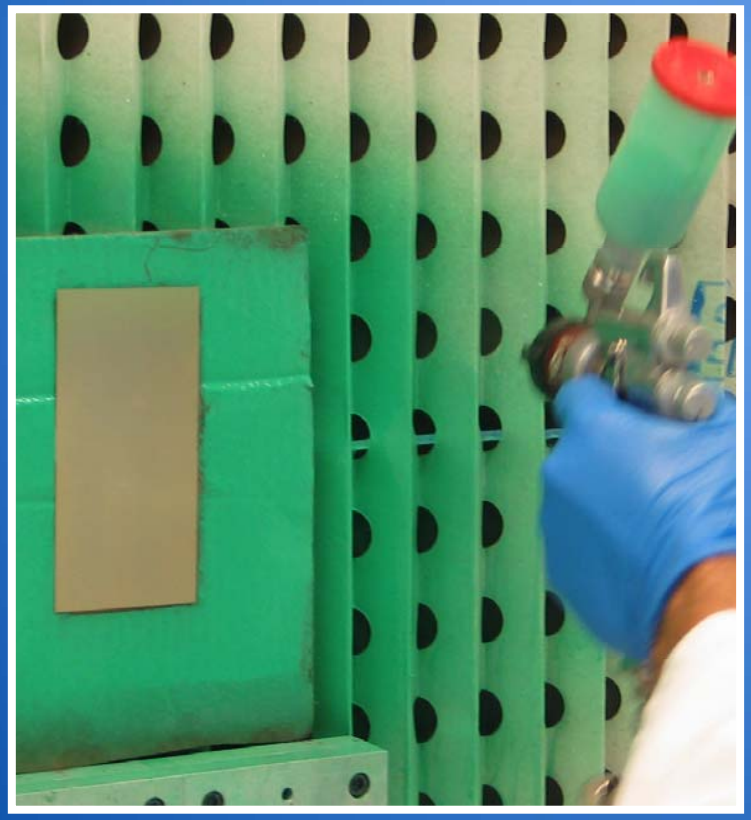
# Spray of Primer

HVLP Spray Gun
Gravity Feed



Test Panel Orientation
In Spray Booth

Final Sprayed
Test Panel

# Key Requirements for UV Curable Top Coating

- Adhesion
  - 5B for dry crosshatch adhesion before and after oil immersion
  - 5A for X-cross adhesion after 24 hours in DI water at room temp
- Impact resistance
  - >40% elongation for aircraft
  - >5% elongation for ground support vehicles
- Low temperature flexibility at -51$^{o}$C by 180$^{o}$ bending
- Fluid resistance in lube oil (MIL-L-23699) at 121$^{o}$C for 24 hours
- Water resistance in DI water at RT for 24 hours
- Hardness
- Color: Federal Standard 595B #36173
  - $\Delta E$ change<1
  - Gloss <5 at 60$^{o}$
- Accelerated weathering by Xeon Arc exposure
  - $\Delta E$ change<1 and gloss change<1 after 3000 hours

# Properties of Foster-Miller's UV Curable Coating for an Aerospace Application-II

| Test | Test Method | Test Condition | UV-Curable Coating Data | Pass/Fail |
|---|---|---|---|---|
| Hardness | ASTM D2240 Shore A | | 80 | Pass |
| VOC | ASTM D5403-93 | RT | 1% | Pass |
| Cure Shrinkage | | In Any Dimension or Volume | None | Pass |
| Percent Elongation @ Break | ASTM D412 Die, C, 0.2 in/min | RT | 36 | Pass |
| | | -65°F | 7 | Pass |
| Water Immersion | | 24 Hours RT | No Marring or Coating Removal | Pass |
| Resistance to Operational Fluids | | 7 Days 49°C, JP-8 Oil, Coolant | No Softening, Wrinkling, Blistering, Loss of Adhesion | Pass |
| | | 7 Days 65°C, Hydraulic Fluid | No Softening, Wrinkling, Blistering, Loss of Adhesion | Pass |
| | | 7 Days 121°F, Lubricating Oil | No Softening, Wrinkling, Blistering, Loss of Adhesion | Pass |
| Flexibility | ASTM D522 | -65°F, 1 in. Mandrel | No Cracks Over 3/16 in. Mandrel | Pass |
| | | RT, 1 in. Mandrel | | Pass |
| Chemical Resistance | ASTM D5402 (using 50 double rubs) | RT | No Significant Loss of Material, Swelling, Hardness Change or Cracking | Pass |
| Storage Stability | GC Head Space Analysis, NMAN Method 2501 | 2 year observation, data taken at periodic intervals | No decomposition | Pass |
| In-Vitro Testing | Corrositex Skin Model | Occular and Dermal Simulated Human Skin | Not corrosive | Pass |

# Properties of Foster-Miller's UV Curable Coating for an Aerospace Application-III

| Test | Test Method | Test Condition | UV-Curable Coating Data | Pass/Fail |
|---|---|---|---|---|
| Condition in Container | | RT | Homogeneous Free From Skins, Lumps an Gelled or Coarse Particles | Pass |
| VOC | | RT | Zero VOC | Pass |
| Cure Time | ASTM D2240 Shore A | 4 Hours Hardness | Instant Cure, 84-87 Shore A | Pass |
| | ASTM D2240 Shore A | 5 Days Hardness | Instant Cure, 84-87 Shore A | Pass |
| Ultimate Tensile Strength, psi | ASTM D412 Die C, 0.2 in/min | -65°F | 1650 | Pass |
| | ASTM D412 Die C, 20 in./min | RT | 450 | Pass |
| | | 250°F | 140 | Pass |
| | | 275°F | 120 | Pass |
| | | MIL-PRF-87252 | 430 | Pass |
| | | MIL-DTL-83133 | 275 | Pass |
| | | MIL-PRF-83282 | 390 | Pass |
| | | MIL-PRF-23699 | 310 | Pass |
| | | AMS 1424 | 350 | Pass |
| | | Heat Cycle | 370 | Pass |
| | | ASTM B117 for 500 Hours | 430 | Pass |
| | | ASTM B117 for 2000 Hours | 354 | Pass |
| | | 100% Relative Humidity per ASTM D2247 @120°F for 30 Days | 480 | Pass |
| | | ASTM G85 Annex A4 | | Future Testing |

# Properties of Foster-Miller's UV Curable Coating for Application III (continued)

| Test | Test Method | Test Condition | UV-Curable Coating Data | Pass/Fail |
|---|---|---|---|---|
| Percent Elongation @ Break | ASTM D412 Die C, 0.2 in/min | -65°F | 35 | Pass |
| | ASTM D412 Die C, 20 in./min | RT | 55 | Pass |
| | | 250°F | 13 | Pass |
| | | 275°F | 9 | Pass |
| | | MIL-PRF-87252 | 42 | Pass |
| | | MIL-DTL-83133 | 27.4 | Pass |
| | | MIL-PRF-83282 | 41 | Pass |
| | | MIL-PRF-23699 | 32 | Pass |
| | | AMS 1424 | 51 | Pass |
| | | Heat Cycle | 25 | Pass |
| | | ASTM B117 for 500 Hours | 52 | Pass |
| | | ASTM B117 for 2000 Hours | 73 | Pass |
| | | 100% Relative Humidity per ASTM D2247 @120°F for 30 Days | 333 | Pass |
| | | ASTM G85 Annex A4 | | Future Testing |

# Properties of Foster-Miller's UV Curable Coating for Application III (continued)

| Test | Test Method | Test Condition | UV-Curable Coating Data | Pass/Fail |
|---|---|---|---|---|
| Flexibility | Coupons shall be tested in Three-Point Bending Mode Over a 6 in. Span with the Coating Facing Down at -65°F | -65°F | no signs of cracking or loss of adhesion in the bend area | Pass |
| | | MIL-PRF-87252 | no signs of cracking or loss of adhesion in the bend area | Pass |
| | | MIL-DTL-83133 | no signs of cracking or loss of adhesion in the bend area | Pass |
| | | MIL-PRF-83282 | no signs of cracking or loss of adhesion in the bend area | Pass |
| | | MIL-PRF-23699 | no signs of cracking or loss of adhesion in the bend area | Pass |
| | | AMS 1424 | no signs of cracking or loss of adhesion in the bend area | Pass |
| | | Heat Cycle | no signs of cracking or loss of adhesion in the bend area | Pass |
| | | ASTM B117 for 500 Hours | no signs of cracking or loss of adhesion in the bend area | Pass |
| | | ASTM B117 for 2000 Hours | no signs of cracking or loss of adhesion in the bend area | Pass |
| | | 100% Relative Humidity per ASTM D2247 @120°F for 30 Days | no signs of cracking or loss of adhesion in the bend area | Pass |
| | | ASTM G85 Annex A4 | | Future Testing |
| Chemical Resistance | ASTM D5402 (Using 50 MEK double rubs) | RT | No Significant Loss of Material, Swelling, Hardness Change or Cracking | Pass |

# Properties of Foster-Miller's UV Curable Coating for an Aerospace Application-III

| Test | Test Method | Test Condition | UV-Curable Coating Data | Pass/Fail |
|---|---|---|---|---|
| Condition in Container | | RT | Homogeneous Free From Skins, Lumps an Gelled or Coarse Particles | Pass |
| VOC | | RT | Zero VOC | Pass |
| Cure Time | ASTM D2240 Shore A | 4 Hours Hardness | Instant Cure, 84-87 Shore A | Pass |
| | ASTM D2240 Shore A | 5 Days Hardness | Instant Cure, 84-87 Shore A | Pass |
| Ultimate Tensile Strength, psi | ASTM D412 Die C, 0.2 in/min | -65°F | 1650 | Pass |
| | ASTM D412 Die C, 20 in./min | RT | 450 | Pass |
| | | 250°F | 140 | Pass |
| | | 275°F | 120 | Pass |
| | | MIL-PRF-87252 | 430 | Pass |
| | | MIL-DTL-83133 | 275 | Pass |
| | | MIL-PRF-83282 | 390 | Pass |
| | | MIL-PRF-23699 | 310 | Pass |
| | | AMS 1424 | 350 | Pass |
| | | Heat Cycle | 370 | Pass |
| | | ASTM B117 for 500 Hours | 430 | Pass |
| | | ASTM B117 for 2000 Hours | | Pass |
| | | 100% Relative Humidity per ASTM D2247 @120°F for 30 Days | 480 | Pass |
| | | ASTM G85 Annex A4 | | Pass |

# Properties of Foster-Miller's UV Curable Coating for an Aerospace Application-IV (2 layers of 1 mil each)

| Test | Test Method | Test Condition | Specification | UV-Curable Coating Data | Pass/Fail |
|---|---|---|---|---|---|
| Dry Adhesion | ASTM D-3359 | Crosshatch | 5B | | Pass |
| Wet Adhesion | | 24 Hours, RT, Water | 4A minimum | No Marring or Coating Removal | Pass |
| Solvent Resistance | ASTM D5402 | RT | 25 double rubs | No Significant Loss of Material, Swelling, Hardness Change or Cracking | Pass |
| Humidity | | 30 Days | Visual adhesion | | In Future |
| Heat Resistance | | 1 hr. @ 250°F | ΔE<1.0, compared with FED-STD-595 #13528 | | In Future |
| Weather | | 500 Xenon Arc | ΔE<1.0, compared with FED-STD-595 #13528 | | In Future |
| Flexibility | ASTM D3924 | Impact testing 3.6 lb x 10 | Elongation not less than 40% | | Pass |
| | ASTM D522 | 1" Mandrel Low Temp at -51°C | No crack | | In test |
| Resistance to Operational Fluids | | 7 Days 49°C, JP-8 | No Softening, Wrinkling, Blistering, Loss of Adhesion | | Pass |
| | | 24 hrs, 65°C, Hydraulic Fluid | No Softening, Wrinkling, Blistering, Loss of Adhesion | | Pass |
| | | 24 hrs 121°C, Lubricating Oil | No Softening, Wrinkling, Blistering, Loss of Adhesion | | Pass |
| Color | ASTM D-2244 | RT | ΔE<1.0, compared with FED-STD-595 #13528 | 0.9 | Pass |
| Gloss | ASTM D-523 | RT | >90 | ~60 | Fail |
| Hiding Power | Color meter | RT | >95% | 95 | Pass |

# Out of the Lab and Into The Factory

# Scale-Up Of Resin Synthesis

3 Liter, 1998 - 2003

2, 15 Liter, 2004 - 2006


2, 30 Liter, 2007

- Sufficient for 25 Gallons of Coating
- 75 L Reactors On Order

# Scale-Up Of Coating Blending

**Beakers and Buckets, 1998 - 2005**

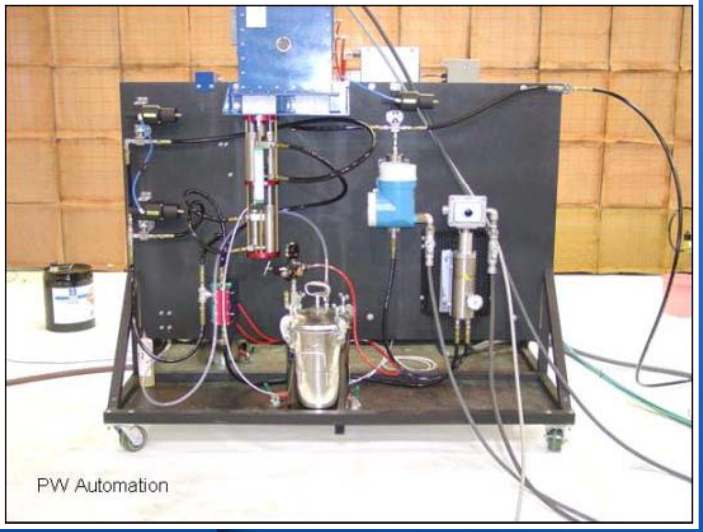
10 Gallon, 2006 - 2007

**100 Gallon Mix Vessel, 2008 and Beyond**

# Robotic Application Of UV Cure Coating


Fluid
Test Stand
Controller

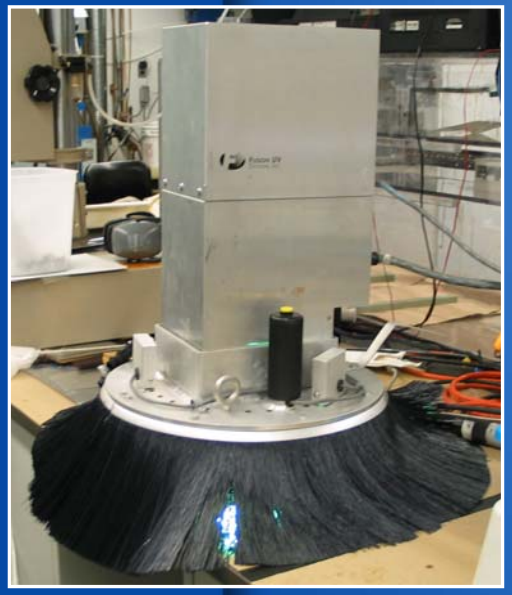
Fluid
Test Stand




## Robotic Spray System Spraying Contoured Mock-up Part

# Robotic UV Curing Of Coatings

## Dem Val Lamp Setup

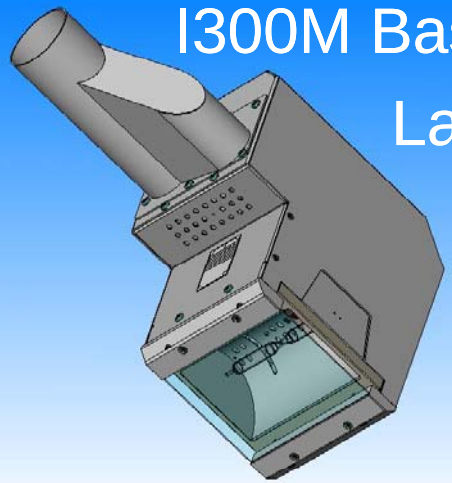


- 2006 Repair DemVal
- Std Bench Lamp
- Hula Skirt Shroud
- Air Cooling Ducts

Standard Bench Lamp Mounted To A Robotic System

## Future Robotic Arm Lamp Concept

I300M Based Lamp



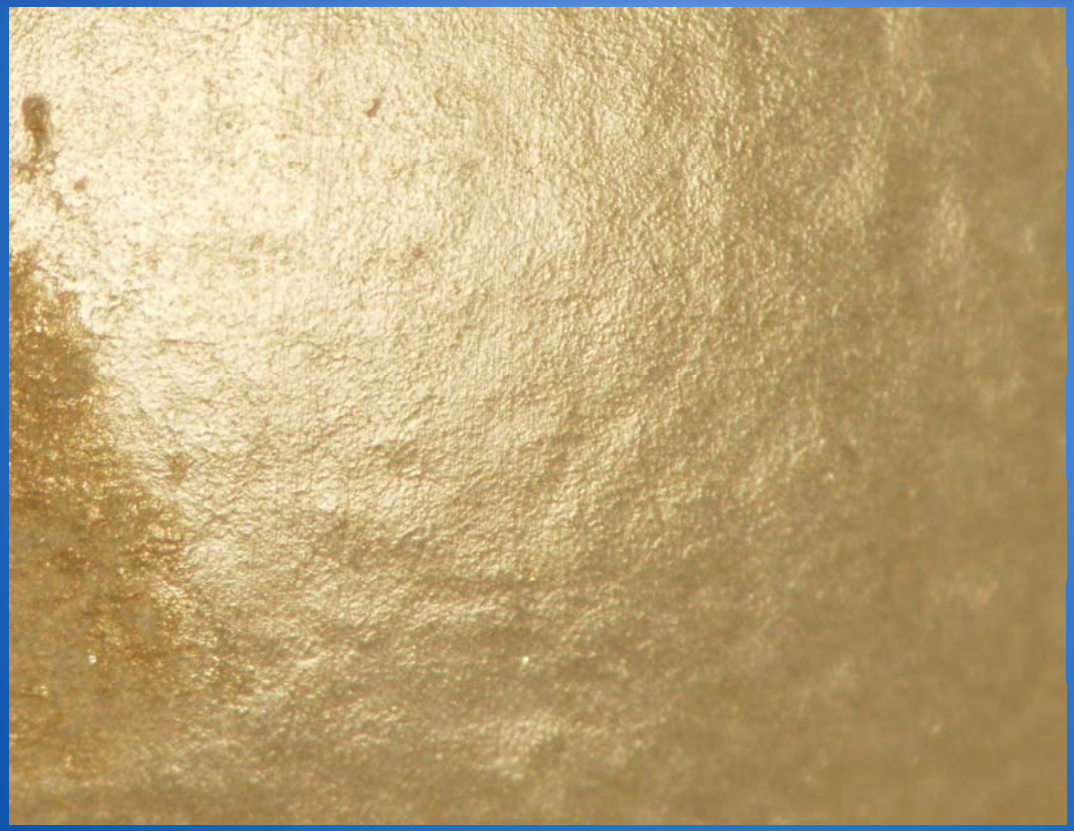
- Quartz Lamp Cover
- Cooling Air Ducting
- Fume Collection
- Robot Arm Mounting

# Conclusions

- Independent performance tests showed FMI's UV-cure topcoat had excellent adhesion, good low temperature flexibility, and borderline oil resistance.
- The initial color and gloss of the coating met the Air Force standards.
- The FMI formulation is suitable for other Air Force applications, including coating ground support vehicles
- FMI Has Scaled One Coating To Large Scale Production Standards
- FMI, PWA, Fusion UV and NGC Have Developed Spray and Cure Systems for Aircraft Production Applications

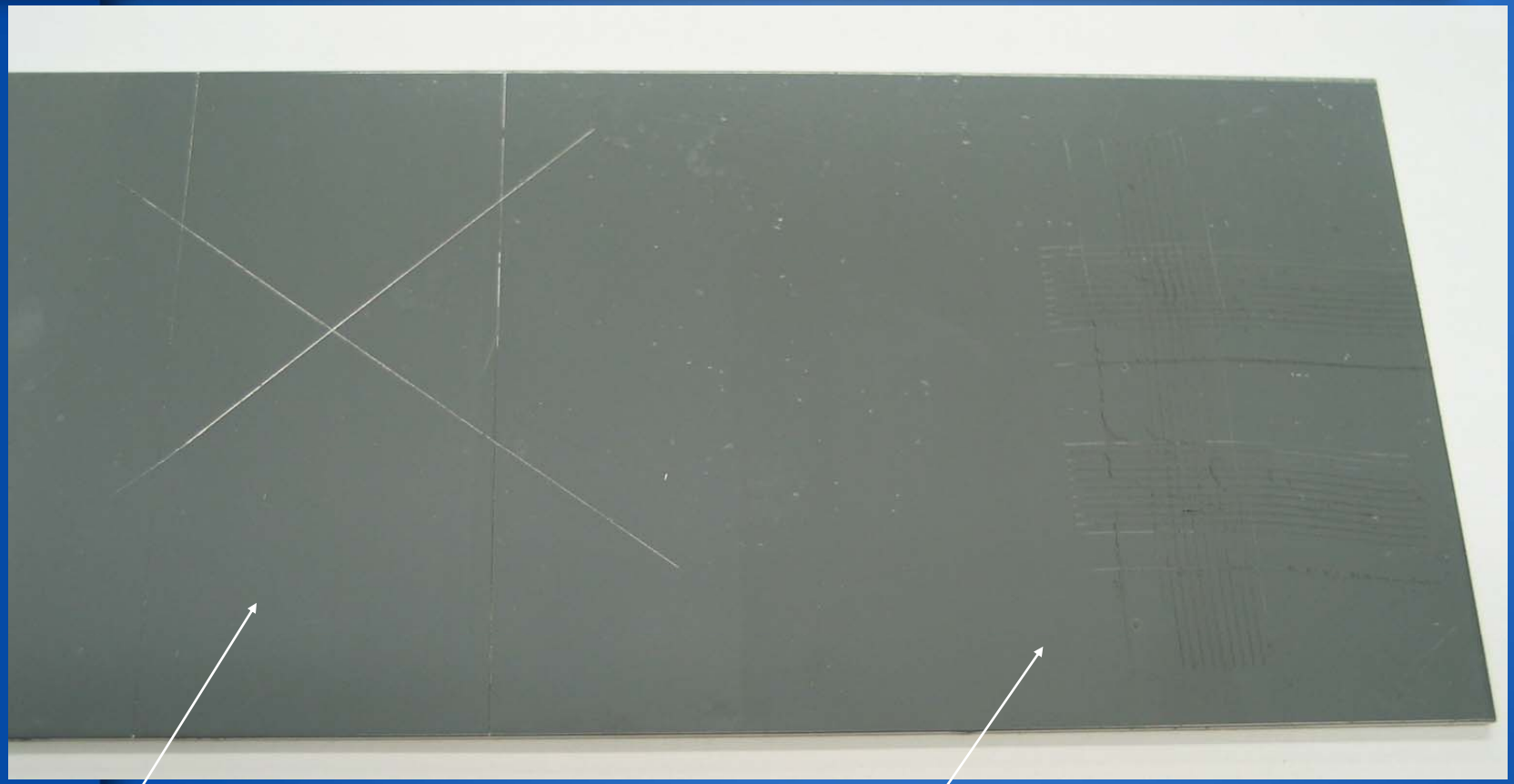
# Back-up Slides

# GE Impact Test of Formulation 7



40% elongation in 10X magnification

# Adhesion of Formulation 7



Wet adhesion

Dry adhesion

# Adhesion of Formulation 7 (continued)